EVALUATION OF BOND CHARACTERISTICS

BY

ULTRASONIC PULSE ECHO TECHNIQUE

By

C. M. BHATNAGAR

A Thesis submitted
in partial fulfilment of the requirements
for the Degree of
MASTER OF TECHNOLOGY

to the

DEPARTMENT OF METALLURGICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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C E R T I F I C A T E

This is to certify that the work

[illegible] OF BOND [illegible] BY [illegible]

PULSE ECHO [illegible] has been carried out by Shri C.M. Bhatnagar under my supervision and it has not been submitted elsewhere for a degree.

(K.L. [illegible])

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A C K N O W L E D G E M E N T

At the outset, I express my deep gratitude to Dr. M.L. Vaidya, Assistant Professor(Metallurgy), I.I.T., Kanpur for his excellent guidance and helpful discussions at various stages in the work without which it would not have been possible for me to carry out the present work.

I would also like to take this opportunity to express my sincere thanks to Dr. K.P. Singh, Head of Department of Metallurgical Engineering and Dr. M.N. Shetty Assistant Professor (Metallurgy), I.I.T., Kanpur for their constant encouragement given to me.

I am also indebted to Shri A.K. Bhattacharyya, Director (M&C) and Shri C.G. Bashyam, Joint Director(Met), Research Designs & Standards Organisation, Ministry of Railways, Lucknow, for their kindness and for the permission extended to me to undergo the M. Tech. programme in Metallurgical Engineering at Indian Institute of Technology, Kanpur.

C.M. Bhatnagar
4.10.76
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A B S T R A C T

Non-destructive testing is an integral and important part of current expanding activities in Materials Technology and is being widely used for quality control. In order to evaluate the bond characteristics by Ultrasonic pulse echo technique experiments were conducted on Antifriction metal bonded to Bronze and steel. The evaluation was based on the theory that transmission of ultrasonic waves will be better through good bonds than through bad bonds. Evaluation was carried out by measurement of electrical conductivity and study of ultrasonic reflections from different zones in bonded plates having White metal lining and Bronze.

Detection and evaluation of bond becomes easier if reflection and transmission coefficients of the materials used are known. The coefficients were determined by using Immersion technique of ultrasonic testing. The experiments have shown that bonds with antifriction lining of thickness 4-5 mm can be evaluated by direct contact whereas for thinner lining immersion testing is recommended.

The comparative study of ultrasonic reflections has revealed that the quotient of back reflection to bond reflection provides a good indication of the quality of the bond. The quotients were corelated with electrical resistivity values and it was established that the greater the quotient, more homogenous will be the bond.

CONTENTS

APPENDICES

EVALUATION OF BOND CHARACTERISTICS BY ULTRASONIC PULSE ECHO TECHNIQUE

INTRODUCTION

In recent years, greater emphasis and demand have been placed for improvement in quality control due to which testing techniques are continually being developed. The increasing use of bonded components has developed a need for a method of evaluating the condition of bond on parts and on completed assemblies. The engineer who uses these components is more concerned with the way in which they stand up to the work required by them.

Non-destructive testing is an integral and important part of current expanding activities in Materials Technology & is being widely used for quality control. The application of ultrasonic waves is generally recognised as one of the major methods employed today in non-destructive testing. Ultrasonics is the name given to the application of sound waves having frequencies higher than 20 KC/Sec. Ultrasonics has been used for investigation of manner of propagation and attenuation of elastic stress waves in solids which enables the study of physical constants and internal defects in the material. At the present time, pulse technique is the most widespread one for testing of material & products by ultrasonics. There is a little information available for evaluating the bond characteristics. The evaluation is based on the theory that transmission of ultrasonic waves will be better through good bonds than through bad bonds. The technique offers a high sensitivity to detect the flaws in the material. This degree of

....2

flaw detection sensitivity is maintained even in the presence of internal stresses in the material, though compressing the defect they diminish the reflection coefficient of ultrasonic waves. The signals observed on the flaw detector screen are the carrier of information about the material under test. The difficulties in testing of a material are due to the lack of information of flaw size or flaw characteristics and lack of univocal setting of testing parameters.

The project work involved evaluation of degree of bond by measurement of electrical conductivity in different zones and study of reflection attenuation of ultrasonic waves. The behaviour of ultrasonic waves has been analysed by studying the sequence of multiple echoes and by comparative examination of pulse echo reflections. The analysis has shown that a good bond produces a clean sequence of echoes. The comparative examinations of reflections have revealed that the quotient of back reflection to bond reflection provides a good indicator of the quality of the bond. The test results also show that in addition to qualitative assessment, a quantitative evaluation can also be made to a certain extent. Both the methods would find their applications in ultrasonic testing of bonds in bearings, clad metals etc. depending on the design and thicknesses of the material. A good mechanically strong bond between the bearing alloy and the supporting shell is very important for best performance.

2. BEARING METALS

2.1 Bearings are used in various types of machinery, under conditions so widely different that the chemical composition and

properties required of bearing alloys cover a very broad range. A bearing alloy well suited for a certain application may be entirely useless in another. A good bearing alloy cannot be defined in a general way, but must be determined according to the type of application.

2.2 Different metals and alloys have different values for sound velocities and acoustic impedance. The latter is defined as the product of sound velocity and the density of the material concer The greater the discrepancy between the acoustic impedance of two metals, the lower is the percentage of sound penetrating and thus such bonds are easier to test by ultrasonic technique. The smaller the difference between the acoustic impedance of the alloys concerned, the more difficult it is to test the bond. Hence for ultrasonic testing, it is necessary to know the chemical composition, sound velocities and acoustic impedance of the material subjected to ultrasonic tests. The values for a few virgin metals and bearing alloys, given below show the difference of sound velocity and acoustic impedance.

TABLE 1 SOUND VELOCITIES & ACOUSTIC IMPEDANCE OF VIRGIN METALS & ALLOYS USED IN BEARINGS.

Material	Sound velocity-Longitudinal waves X 10^3 m/Sec.	Acoustic impedance X 10^6 kg/m^2Sec
Lead	2.16	25
Tin	3.32	24
Copper	4.7	42
Aluminium	6.32	17
Brass	3.83	33
Zinc	4.17	30
Tin base alloy*	3.28	24.3
Lead base alloy*	2.4	23.5

*Typical composition

2.3 A brief review is given covering commercially used bonde bearing metals.

2.3.1 WHITE METALS:- The most widely used bearing metals are white metals, both those on a tin-base and those on a lead-base The widespread use of white bearing metals is due, firstly, to their low coefficients of friction, and secondly, to the high absorption capacity for oil as lubricant. The system that has been chosen for study is lead-base white bearing metal with a cast bronz backing plate.

(a) Tin-base alloys:- The tin-base bearing materials, known commercially as "Babbitts" are substantially alloys of tin,antimony & copper to which may be added as much as 30% lead for the purpose reducing their cost. Zinc, aluminium, arsenic, bismuth and iron are limited in amount. The structures of these alloys vary in accordance with their composition. The tin-base alloys have lower resistance to fatigue than lead-base alloys and are normally used in low-load situations. On the other hand, tin-base alloys are easier to bond and have excellent anti-seizure qualities. Further, they resist corrosion much better than lead-base bearing alloys.

(b) Lead-base alloys:- The lead-base bearing alloys are of two types : (i) Alloys of lead,tin,antimony & in many instances, arsenic

(ii) Alloys of lead, calcium, tin and alkaline earth metals.

The properties of lead-base bearing materials varies with composition. In the absence of Arsenic, the microstructure of these alloys consists of cuboid-shaped primary crystals of Sb Sn or of antimony embedded in a ternary mixture of Pb-Sn-Sb Sn in which lead forms the matrix. The antimony content is 9-15% and

if it exceeds the alloys becomes too brittle and is not useful as a bearing material. The addition of arsenic has the advantage of improvement in the mechanical properties, particularly at elevated temperatures. The lead-base bearing alloys are considered low-cost substitutes for tin-base alloys. It has been found that when the lead-base alloys are used in reduced thicknesses the resistance to fatigue is approximately equal to that of the tin-base alloys and there is also not much difference in anti-seizure characteristics.

2.3.2 Cadmium-base alloys: These have a low coefficient of friction, good oil absorption, good heat dissipation and high static and dynamic load carrying capacity. The alloy mainly consists of 95-98% cadmium, 2.0 - 1.0% nickel. Silver, copper, tin, lead, zinc are in very small percentage. These alloys bond readily with steel. The bond is strong and ductile due to presence of nickel in the bearing alloys.

2.3.3 Copper-lead alloys: The alloys are used with steel-backed bearings mostly in aircraft and autometive industry and contain copper 60-75%, lead 25-40%, silver 1.5% max. and other elements as zinc, tin, phosphorus. The higher the lead content the lower is the fatigue strength and higher the anti-frictional characteristics.

2.3.4 Aluminium-base alloys: These bearings are chiefly used in the form of homogenous single parts. Processes have also been developed for bonding the aluminium bearing alloys to steel backing material, but bonding difficulties have been experienced due to the differences between the coefficients of expansion of the two metals. The alloys mainly consist of

...6

85-95% aluminium, 6.5 - 8.0% tin and other constituents viz. copper, nickel, cadmium in small percentages.

3. BONDING CHARACTERISTICS AND SIGNIFICANCE

The bi-metallic bearing is a means of supporting a shaft or other moving part. The composition is such as to cause minimum amou of loss of power by friction in the bearing. The motion of one piec of machine relative to another may be in a straight line or it may b rotary or oscillatory. Some type of material are more easily compressed under load than others and therefore it is essential to choose a metal hard enough to stand up to the pressure likely to l put upon it and at the same time to give it a backing sufficiently strong to prevent undue yielding. In any bearing there is always friction and therefore certain amount of wear takes place. The use of lubricants reduces the coefficient of friction. Moreover it is essential that the adhesion between the bimetals shall be as perfect as possible. The incomplete adherence of the two bimetals may lead to the following main consequences:-

3.1 HOT BEARINGS : In case of bearings having white-metal lining it has been seen that a major cause of hot bearing is due to incomplete adherence of white metal lining to the body of the shell. Partly this may be due to the shrinkage of the white metal, but more often it is due to careless tinning of the shells before metalling, thereby resulting in an inadequate bonding. The spaces left in this way between the shell and the lining become filled with oil of which the thermal conductivity is many times less than that of the white metal. Thus the heat generated in the bearing is dissipated to the shell by conduction much more slowly than if good metallic bond exists.

...7

3.2 SEIZING OF BEARINGS: The phenomenon of seizing is the usual result of a hot bearing. The bearing seizes not when the film ceases to exist but when the stress on the lubricant oil reaches a limit which is a function of the viscosity and other properties of the oil. In addition to the oil, the material of which the bearing is made and the adhesion between the white metal and the shell are also important factors. Seizing of the bearings usually occurs due to warming up of the bearing housing. The bearing metal expand at a rate different from that of the journal or shaft which does not get heated to the same extent owing to its far greater mass and greater heat dissipation. This would lead to excessive heating of the bearing and will lead ultimately to the melting of the lining. The extent of the damage may be limited by choice of the bearing metal, bond strength and mechanical properties of bearing surface. The presence of bad bond will offer lower conductivity and hence may cause serious problem.

3.3 SHEARING OF BEARING METAL: The shearing of bearing metal takes place if the strength of the bond is not adequate. If the shearing forces exceed the strength of the bond it breaks down and seizing occurs even though at the time of the breakdown the oil film is of appreciable thickness. The faulty adhesion is one of the main reasons for cracking of the metallic lining. Once a crack has formed oil gets beneath the metal and seems to act as a lever to remove further sections and so reduces the amount of metal adherent more and more. The cracks generally begin on the surface and work downwards but they do not necessarily pass through the metal to the base shell. Cracking of metallic lining results

...8

due to the lack of adhesion and hence it is essential that the adhesion between the white-metal and the shell shall be as perfect as possible. To rely mainly upon mechanical anchoring devices such as dove tails and pegs is unwise as these are difficult to tin properly and sooner or later fail to function as they should. Instead greater care should be taken with the tinning operation followed by adequate quality control measure by non-destructive testing.

4. REVIEW OF METHODS FOR EVALUATION OF BOND CHARACTERISTICS

The methods for testing of bonds in bimetals can be classified as

(a) Destructive tests

(b) Non-destructive tests

4.1 DESTRUCTIVE TESTS:- Bond suitability for the intended application can be assessed by testing the bond under the specific stresses and conditions encountered in actual service. In order to determine the maximum bond performance these stresses are increased to the point of bond failure. These tests can be applied for spot checking a certain percentage of bearings. The test specimen has to be made of the same materials and with the same type of joint structure as the assembled product for which the bonded component is intended.

4.2 NON-DESTRUCTIVE TEST:- Non-destructive testing is an integral and important part of current expanding activities in materials technology. Testing bonds by non-destructive methods is particularly suited for quality control and inspection. The methods are:-

...9

4.2.1 TAPPING METHOD:- This is probably the oldest form of non-destructive test applied to any metal-to-metal fit. A tapping hammer is struck lightly against the component and the resulting tone is analysed by ear to detect the tone differences. Inadequate bonds give a hollow sound. The result of this inspection method varies widely from inspector to inspector and from day to day depending upon the ambient noise level, attitude of the inspector, internal structure of the bonded assemblies etc.

This technique has been refined somewhat by the introduction of a solenoid-operated tapping hammer, used with microphone pick ups. The signals from the pick up are either transmitted to the headphones of the operator or the signals analysed for the amplitude and frequency components of the tone generated by the hammer. With both of these methods corelation is difficult because of wide scatter in information and none of these can detect voids which are very small and covered by the thikkness of the adherent. The method is generally regarded as a rough checking method.

4.2.2 RESISTIVITY MEASUREMENTS:- The method is based on the measurement of resistivity at different locations in the component. A moving electrode head enables four co-linear points to be brought into contact with the flat surface of the specimen. The outer two electrodes carry a small measuring current and the inner two electrodes meter the appropriate potential difference. Although the current flow in such an assembly is not liner Valdes(1) has computed the form of variation of potential and current for various probe spacings and resistivities of material and from the

....10

experimental results resistivity can be calculated. The electrode assembly is traversed along or across the bearing surface to check the variation of resistivity with distance. The bond evaluation suffers from the disadvantage that resistivity also varies with impurity content and non-uniformity in thickness of the bearing metal. A variation of impurity content or inadequate bond may be examined in this way and a major change of value occurs over a short distance may indicate a major fault or inadequate bonding. The method can be used for a rough estimation of quality of bond.

4.2.3 ULTRASONIC METHODS:- Ultrasonics is the technology of sound as applied to problems of measurement, control and processing, using sound waves having frequencies higher than 20 KC/S. The application of ultrasonic waves is generally recognised as one of the major methods employed today in non-destructive testing. The technique utilises longitudinal, transverse or surface waves whose velocities are functions of the physical constants of the material conducting the ultrasonic waves. The evaluation by ultrasonic method is based on transmission of longitudinal waves through metallic bonds and their subsequent reflection from bad or porous bonds. Ultrasonic energy in the form of high frequency sound waves is introduced into the structure and its behaviour is analysed in order to have the evaluation of bond. By comparing recorded signals of good or defective bonds with those being tested conclusions can be drawn as to their quality. The technique has been dealt in detail in subsequent para.

...11

4.2.4 OTHER METHODS:- Other non-destructive tests include x-rays, Gamma rays, Infrared and photographic Scanning methods to detect defective bonds. None of these however give a conclusive indication in regard to the evaluation of bond in bimetallic components.

5. ULTRASONIC TECHNIQUE FOR TESTING OF MATERIAL

Ultrasonic testing of materials makes use of mechanical waves composed of oscillations of discrete particles of material. The measurements are made with plane waves which originate from a source having a plane surface which vibrates with simple harmonic motion. When the source vibrates in the direction of wave motion, longitudinal waves are propagated. These waves give rise to alternate compressions and rarefactions. The discussion is confined to such vibrations, as these have been used for study.

5.1 VIBRATION MODEL WITH LONGITUDINAL WAVES

The model of a solid body can be visualised as consisting of many separate particles of material only if it is homogenous throughout and if it shows the same elastic behaviour in all directions. When the body is stressed by compression or tension, below its elastic limit, it behaves like a spring model i.e. the motion carried out by a small mass attached to a spring. The nature of this oscillation is sinusoidal, the path recorded as a function of time being a sine curve.

...12

5.1.1 FREE VIBRATION MODEL:- The propagation of sound waves involves the generation of vibrations of the body which provides the source of energy and of the elementary particles in the medium through which the waves are passing. Although these vibrations can take one of a number of different forms, in nearly all cases with which we shall be concerned they can be related to the oscillations of a mass, M, suspended from some fixed support by a spring having a compliance, Cm i.e. the displacement per unit restoring force. Free vibrations take place when the mass is displaced and then released to oscillate without the aid of any external agency; forced vibrations occur when the mass is caused to undergo sustained oscillations caused by some applied periodic force.

Let consider the mass M, as in fig.1 be displaced by an amount xo, such that the spring is strained within the elastic limit, and then released. The mass, in the absence of damping, will then execute simple harmonic vibrations with a frequency, $f_r = w_f/2\pi$, given by the equation:

$$w_f = (MCm)^{-1/2} \qquad \ldots\ldots\ldots (1)$$

The equation of motion in this instance is:

$$M\frac{d^2x}{dt^2} + \frac{x}{Cm} = 0 \qquad \ldots\ldots\ldots (2)$$

Here, x represents the displacement of the mass at any time, t, and the solution to equation (2) is given by:

$$x = xo \cos w_f t \qquad \ldots\ldots\ldots (3)$$

....13

where xo is called the displacement amplitude of the mass. In practice, frictional effects cause the motion to be damped and, provided that this damping is not too heavy, oscillations still occur but the amplitude decreases with time. For small damping the frictional force is proportional to the velocity, the constant of proportionality being Rm, the mechanical resistance. Equation (2) can then be represented as

$$M\frac{d^2x}{dt^2} + R_m\frac{dx}{dt} + \frac{x}{C_m} = 0 \quad \ldots\ldots\ldots \quad (4)$$

The frequency is lower than that given by equation (1) but the difference is usually negligible and can be ignored. To the first order, the solution to equation (4) is:-

$$x = x_o \exp.(-a't) \cos \omega t \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

where $a' = R_m/2M$.

This equation is represented in Fig.1 as a damped harmonic curve having exponential envelopes. The amplitudes of successive peaks are given by $x_0, x_1, x_2 \ldots\ldots x_n$ at times 0, T, 2T.... nT, where T =1/fr, represents the time period and n is an integer. The logarithmic decrement, δ, is given by the expression:

$$\delta = a'T = R_mT/2M \quad \ldots\ldots\ldots \quad (6)$$

and it can be seen that

$$\exp.\delta = \frac{x_0}{x_1} = \frac{x_1}{x_2} = \frac{x_2}{x_3} = \ldots \frac{x_{n-1}}{x_n} \quad \ldots(7)$$

...14

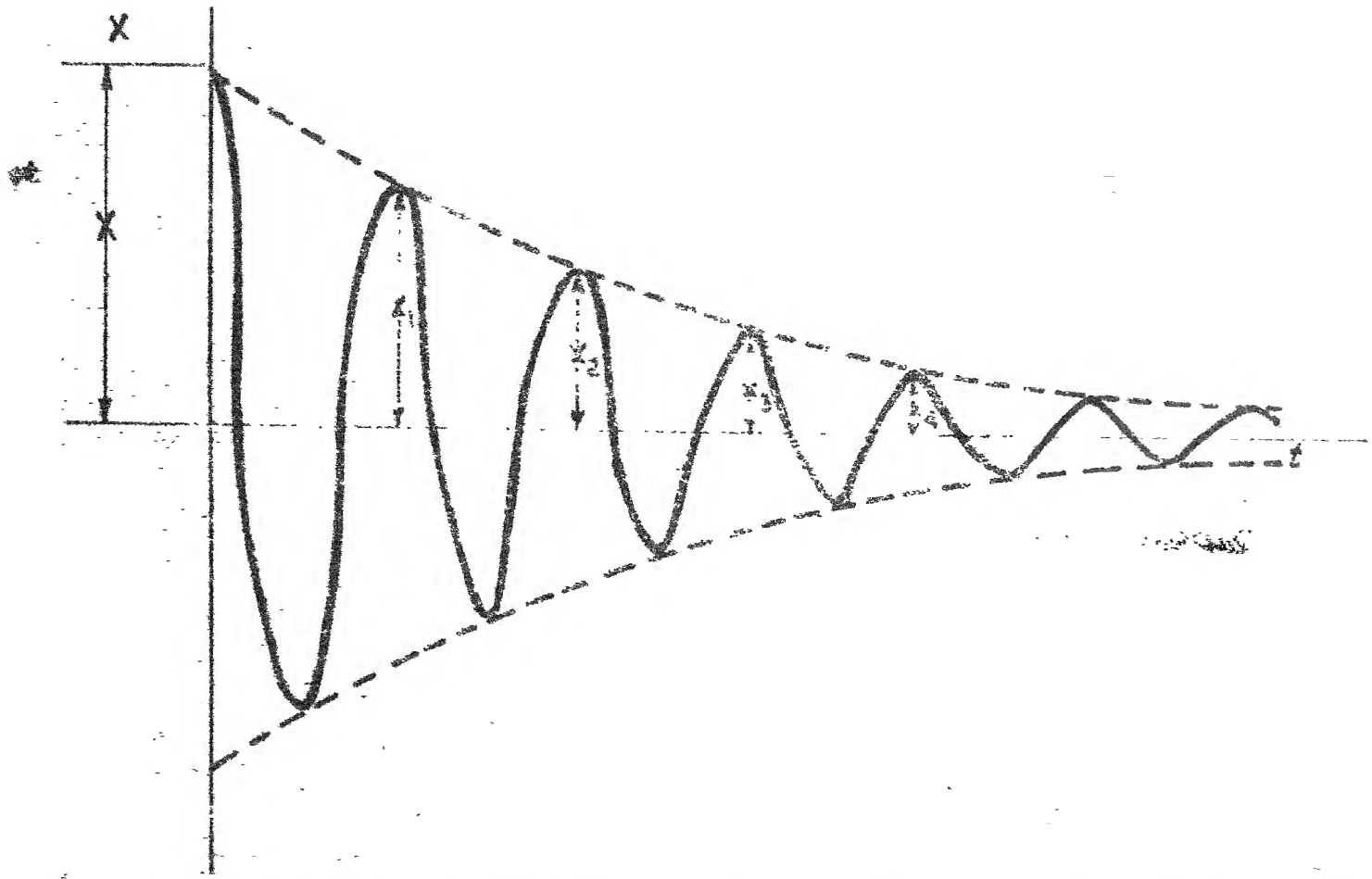


FIG. 1. RELATIONSHIP BETWEEN DISPLACEMENT AND TIME FOR DAMPED HARMONIC VIBRATION

5.1.2 ENERGY OF FREE VIBRATIONS

The total mechanical energy W_m of the vibrating system at a given time is given by

$$W_m = \tfrac{1}{2} Mu^2 + \tfrac{1}{2}\left(\frac{x^2}{C_m}\right) \quad \ldots\ldots\ldots\ldots \quad (8)$$

where $u = dx/dt$ represents the velocity of the mass.

The first term on the right-hand side of equation (8) represents the kinetic energy of the mass and the second term the potential energy stored in the spring. In the absence of damping the Principle of Conservation of energy shows that W_m remains constant at all times. Differentiating equation (3) we get,

$$u = u_o \sin w_r t \quad \ldots\ldots\ldots\ldots \quad (9)$$

where u_o represents the velocity amplitude.

From equations (8) and (9), when $x = 0$, $u = u_o$, and when $u = 0$, $x = x_o$, i.e. when the potential energy of the spring is zero the kinetic energy of the mass assumes its maximum value, $\tfrac{1}{2} Mu_o^2$, and when the potential energy of the spring reaches its maximum value, $\tfrac{1}{2}\left(\frac{x_o^2}{C_m}\right)$, the kinetic energy of the mass is zero.

Hence, we have:

$$W_m = \tfrac{1}{2} Mu_o^2 = \frac{\tfrac{1}{2} x_o^2}{C_m}$$

Where frictional losses do occur, the energy losses can be related to the logarithmic decrement as expressed by equation (7). Thus the fractional loss of energy per cycle is given by:

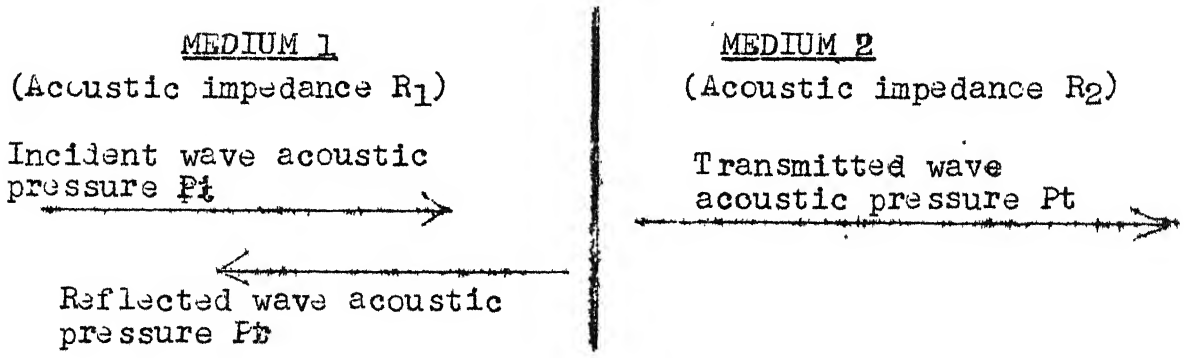
$$\frac{\Delta W_m}{W_m} = \frac{W_{n-1} - W_n}{W_{n-1}} = 1 - \frac{x_n^2}{x_{n-1}^2} = 1 - \exp.(-2\delta) \simeq 2\delta \quad \ldots(10)$$

where δ is small.

....15

5.1.3 ULTRASONIC WAVES ON BOUNDARIES AT PERPENDICULAR INCIDENCE

In practice every substance has its boundary where the propagation of the wave is disturbed. If the material concerned borders on an empty space no wave can travel beyond the boundary because the transmission of such a wave always requires the presence of particles of material. At such a free boundary the wave will therefore return in one form or another in the form of reflection, whereas on a rough boundary scattering of waves will take place and the resultant reflection will be of comparatively less amplitude. This forms the basis of bond evaluation by normal incidence of ultrasonic waves. To understand this, let us consider a beam of plane waves incident normally to a plane boundary which separates two media, 1 and 2, having characteristic impedances, R_1 and R_2 , respectively. In general part of the incident sound energy is reflected back into medium 1 and the remainder transmitted into medium 2, as shown below:-



In the two media let Pi, Pr and Pt represent values of acoustic pressures for incident, reflected and transmitted waves, respectively, and Vi, Vr, and Vt the corresponding values of particle velocity. If the waves are sinusoidal in form and the medium is non-absorbent, we have:

...16

$$Pi = A_1 \sin (wt - k_1x) = ViR_1 \quad .... \quad (11)$$

$$Pr = B_1 \sin (wt + k_1x) = VrR_1 \quad .... \quad (12)$$

$$Pt = A_2 \sin (wt - k_2x) = VtR_2 \quad .... \quad (13)$$

The symbols A_1, B_1 and A_2 represent pressure amplitudes and k_1 and k_2 the wave numbers, $2\pi/\lambda$ for the two media. x is positive in the direction of the incident beam. In equation (12) the change in signs appended to both x and R_1 indicates that the reflected wave travels in the negative direction of x.

At the boundary, the following conditions must be satisfied at all times:

(a) in order to preserve continuity, the pressure at the boundary must be the same on both sides,

i.e.: $$Pt = Pi + Pr \quad ..... \quad (14)$$

(b) particle velocities normal to the boundary must be equal on both sides, otherwise the two media would no longer remain continually in contact with one another i.e.:

$$Vt = Vi + Vr \quad ..... \quad (15)$$

In order to know, at the boundary,

(i) The Reflection coefficient $\alpha_r =$ Acoustic intensity of the reflected wave / Acoustic intensity of the incident waves

(ii) Transmission coefficient $\alpha_t =$ Acoustic intensity of the transmitted wave / Acoustic intensity of the incident wave.

let us consider at boundary i.e. when x = o, the equations (14) and (15) become 17

$$A_2 = A_1 + B_1$$

$$\& \; R_1 A_2 = R_2 (A_1 - B_1)$$

Thus
$$\frac{Pt}{Pi} = \frac{A_2}{A_1} = \frac{2R_2}{R_1 + R_2} \qquad \ldots\ldots (16)$$

and:
$$\frac{Pr}{Pi} \quad \frac{B_1}{A_1} = \frac{R_2 - R_1}{R_1 + R_2} \qquad \ldots\ldots (17)$$

The accustic intensity is proportional to the square of amplitude, so from the above relationships, we can represent Reflection coefficient α_r and transmission coefficient α_T as below:

Reflection coefficient $= \alpha_r = \left(\frac{R_2 - R_1}{R_1 + R_2}\right)^2 \qquad \ldots\ldots(18)$

& Transmission coefficient $= \alpha_t = \frac{4 R_1 R_2}{(R_1 + R_2)^2} \qquad \ldots\ldots(19)$

The equations (18) and (19) show that, where R_1 and R_2 are equal, α_t reaches its maximum value of unity and α_r becomes equal to zero. These are ideal cases, but, in practice, good accustical coupling between the media occurs when R_1 and R_2 have values of the same order of magnitude, i.e. the value of α_t lies between 0.1 and unity. A poor degree of coupling is experienced when the orders of magnitude of R_1 and R_2 differ considerably.

5.2 PULSE TECHNIQUE FOR ULTRASONIC TESTING OF MATERIALS

The pulse technique, in its simplest form, consists of sending a short train of sound waves through the material and subsequently receiving the waves. The waves may be sent by transmission through the specimen and received at the other face or transmitted and received after pulse echo reflection from the boundary of the material or from a defect. For the transmission method the receiver is placed at a measured distance from the source but for the echo method a reversible transducer serves as both source and receiver, a reflector being used to return the pulses. The speed of sound in the medium is then determined from the time of travel of the pulse over a given acoustic path length. Firestone [2,3.] in 1940 was the first to recognise the importance of the pulse echo method for non-destructive testing, particularly for the location of flaws. Subsequently the technique gained importance and increasingly used for non-destructive testing.

5.2.1 PRINCIPLE OF THE TECHNIQUE:- In this, the ultrasonic waves are transmitted into the material under examination, by excitation of a piezo-electric crystal. The frequency of vibration normally used is 0.5 MC/Sec. — 10 MC/Sec. The crystal or "probe" is coupled to the test material by a film of oil, water or grease and can be made to send the waves, at normal incidence or at any angle so that it can be used to detect the flaws. The transmission is not continuous, but is pulsed, so that in the period between the pulses the crystal can be used to detect the return of waves which have

...19

been reflected from the defects or boundary lying in the path of the beam. The waves are converted into electrical impulses and displayed as signals or echoes on the screen of a cathode-ray tube. The ultrasonic flaw detector provides this facility.

5.2.2 EQUIPMENT FOR THE PULSE TECHNIQUE :- The ultrasonic flaw detector consists essentially of an oscillograph with the correlated generators for the deflection voltages, the transmitter unit and the amplifier. The electric voltage pulses of the transmitter are supplied to the probe through a test cable and return, after reflection, to the instrument where they are amplified and displayed. The simplified block diagram for the type of instrument used is shown in fig.2. For most applications the echo method employing a single reversible transducer is used but sometimes, for example when the medium is highly attenuating, separate transmitting and receiving crystals are placed at opposite sides of the specimen.

The instrument is operated by means of a trigger which activates simultaneously the time base control and the pulse generator. At the same time a signal is passed via the amplifier to the Y-plates of the cathode ray oscilloscope; a peak A, thus appears at the left-hand side of the screen. Triggering occurs at regular intervals with a frequency which may range from about 50 to 1,000 c/s. Where a frequency of 50 c/s is used it is common practice to use the A.C. mains as a trigger.

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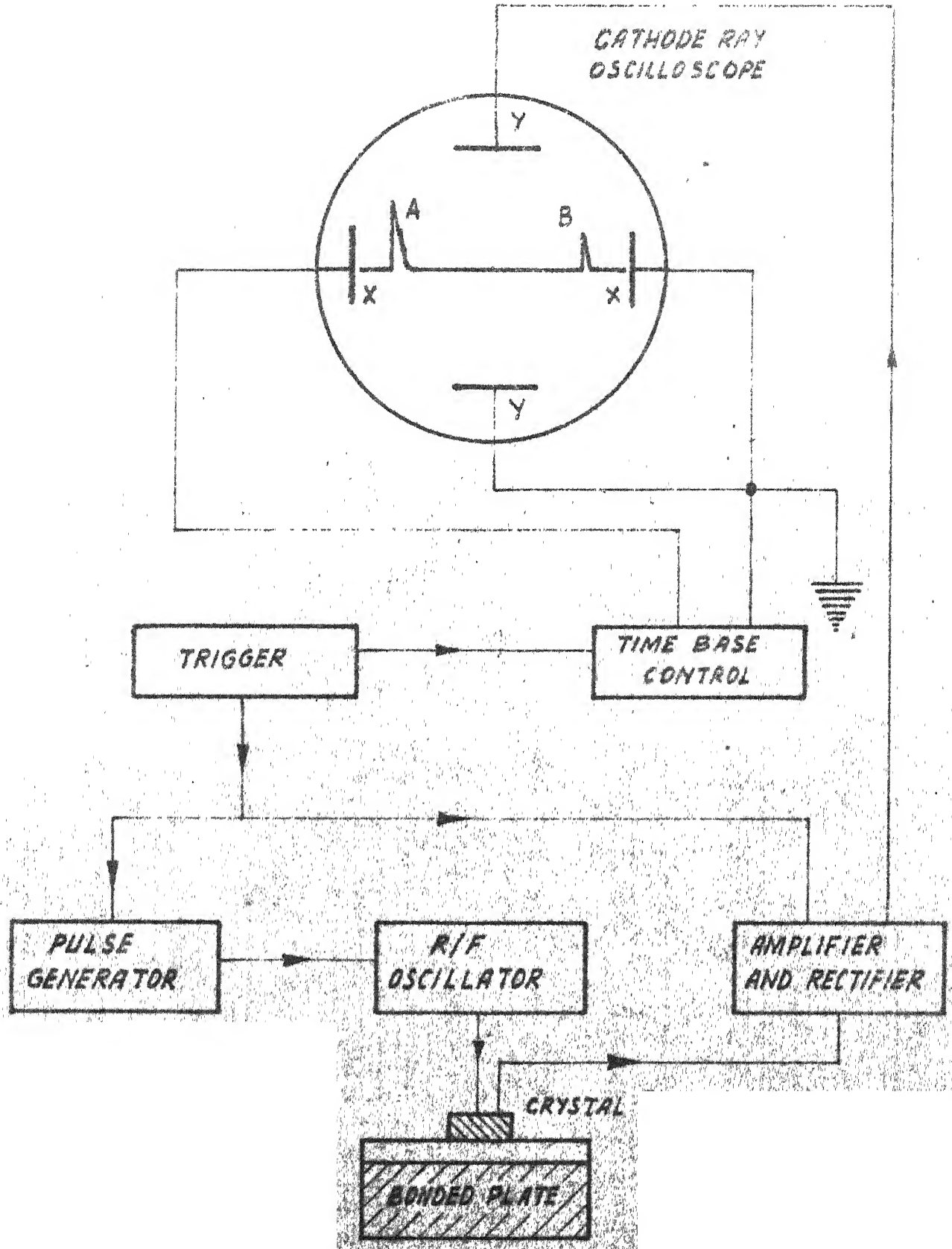

FIG 2. DIAGRAM OF THE EQUIPMENT USED FOR THE PULSE TECHNIQUE.

The transmitting crystal is excited at one of its resonant frequencies by means of the radio-frequency oscillator, the output of which is controlled by the pulse generator. In this way, intermittent trains of ultrasonic waves are propagated through the sample. These waves are, in due course, picked up by the receiving crystal and the induced electrical signals are amplified, rectified , and fed to the Y-plates of the oscilloscope to give the peak, B. Because of the time delay due to the sound pulse travelling through the solid, the peak, B, is displayed further along the time base. Since the time-base frequency is synchronized with the pulse repetition frequency, the peaks, A and B, remain stationary on the screen. Where the time base is calibrated, the time taken for the pulse to travel through the specimen is determined by measuring the distance between A and B. The speed of sound is then obtained by dividing the measured value of the acoustic path length by the time obtained in this way. The time base may be calibrated either by feeding a signal from a standard frequency source to the Y-plates of the oscilloscope or by sending pulses through a material for which the velocity of sound is known.

The attenuation is obtained by measuring the relative heights of the peaks, B, for different path lengths. The path length cannot be varied continuously for solids but if the time base is contracted sufficiently, a number of equally spaced peaks of decreasing heights, each representing a consecutive reflection, will be observed. This is called the

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multiple-echo method. Ideally, the peak height should decrease exponentially with distance in the same way as the acoustic amplitude as shown in equation (7) and the absorption coefficient thus obtained from the logarithmic decrement of the peaks.

6. EXPERIMENTAL PROCEDURE

6.1 SAMPLE PREPARATION:-

6.1.1 The experimental work was carried out on the bonded test plates having base plate of bronze with a top lining of antifriction metal.

Bronze conforming to IS 1458-65 Class V " Specification for Railway Bronze ingots & castings" was melted and eight number of base plates were cast. The plates were machined to size 150 x 100 x 25 mm with plane parallel faces. The drillings from a cast plate were analysed. The composition is as below:-

Copper	-	80.5%
Lead	-	5.46%
Zinc	-	4.5%
Tin	-	6.85%
P	-	.032%
Sb	-	0.18%

6.1.2 Circular test blocks of bronze and antifriction metal as in Fig.3 were also cast and machined to 25 mm thickness for standardisation of test procedure and measurement of velocity of sound waves.

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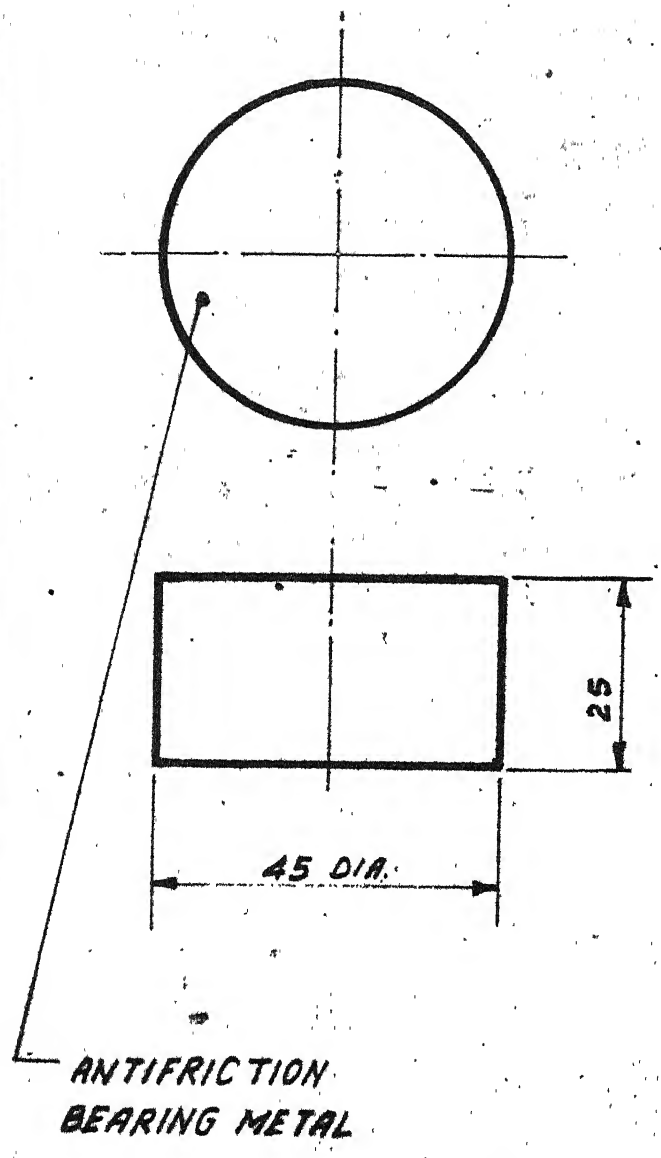

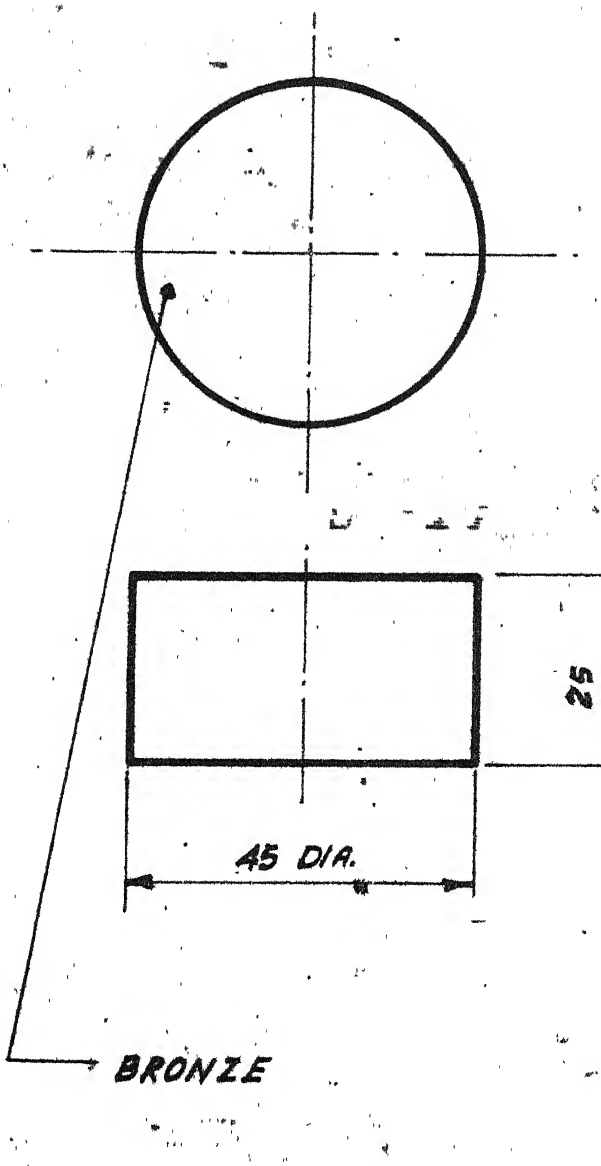

FIG. 3. CALIBRATION BLOCKS FOR MEASUREMENT OF VELOCITY AND TIME BASE.

6.1.3 The base plates, free from defects, were tinned and white metalled on one of the machined faces. The places, where bad bonding was required, were coated with refractory coatings. The procedure adopted was:-

(i) The base plates were preheated to a temperature 280°-300°C and fused flux mixed with water, was coated on the machined surface. Tin solder as commercially available was rubbed over the surface with fluxing the surface as and when required, so as to achieve a uniform thin tin coating. The fused flux, used was of the following composition:

(a) Zinc chloride - 8 parts by wt.

(b) Sodium chloride - 2 parts by wt.

(c) Ammonium chloride- 1 part by wt.

(ii) The above process was repeated at places where lower tinning temperature gave rise to a non-uniform streaky appearance due to excessive accumulation of tin, as it would have effected the bonding desired.

(iii) White metal conforming to IS 25 grade 5 "Specification for Antifriction Bearing Alloys", was melted and the lining of base plates was done in a metal jig, fabricated from mild steel plates. The lining was done keeping the plates in horizontal position. During pouring of the white metal, care was taken that no dross went with the metal into

...23

the lining to give undesired defects.
The chemical analysis of the white metal as analysed was

Lead	- 72.4%
Sn	- 0.85%
Sb	- 16.45%
As	- 1.0%
Cu	- 0.7%

6.1.4 The thickness of the white metal lining plates was kept 5 mm. The six plates were given the test sample No. A,B,C,D,E & F. The zones in each plate were marked as A-1,A-2 ..... to F_1, F_2, F_3 .....
The dimensions of the test plates and marking of zones for test purposes are shown in fig.4.

6.2 ELECTRICAL RESISTIVITY MEASUREMENT

6.2.1 The measurement of electrical resistivity characteristics of bond was done using the "Bondmeter Mark 3" manufactured by M/s Hoyt Metal Company, U.K. The equipment can be used with antifriction white metal upto 10 mm thick and consist of (a) Four electrode surface probe (b) Amplifier (c) Ammeter (d) stabilised power supply (e) Probe current and meter setting controls. The principle of operation is based on what is known as the "Surface Probe technique" whereby a current is caused to flow between two electrodes placed on the

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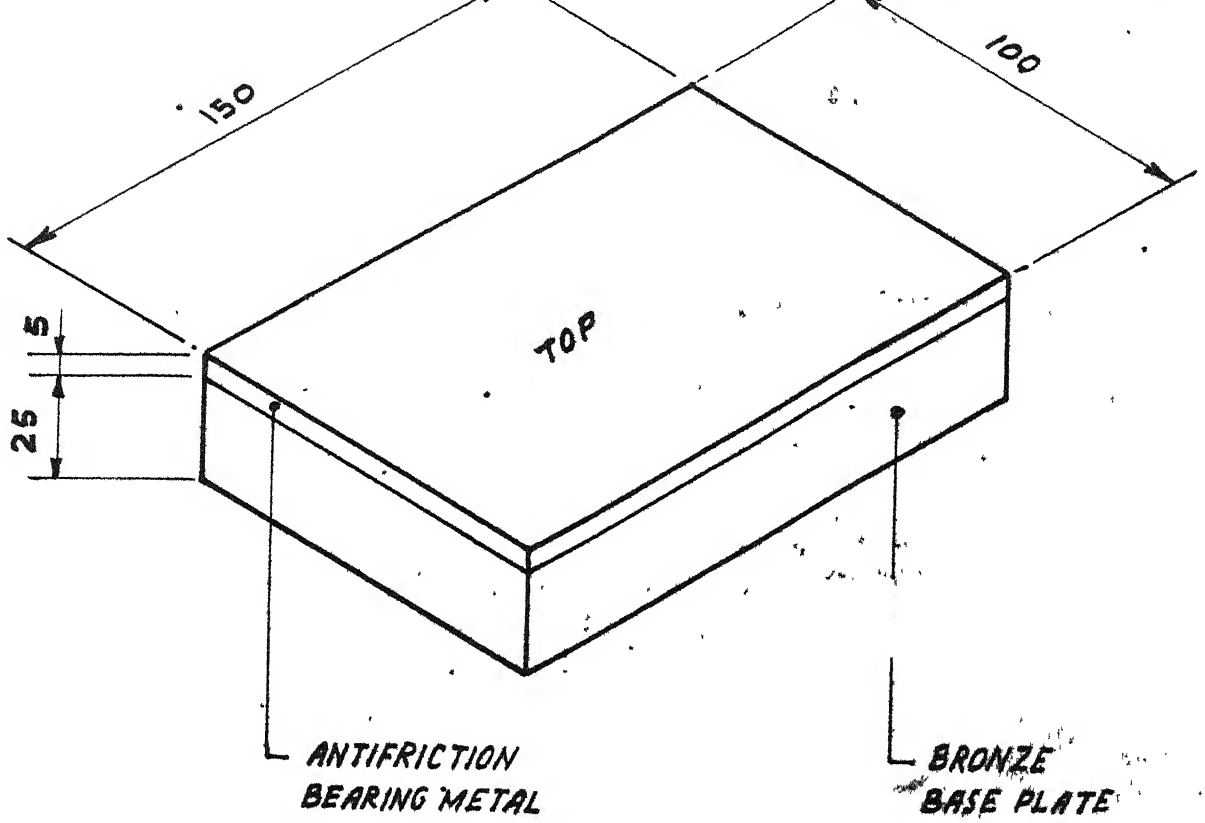
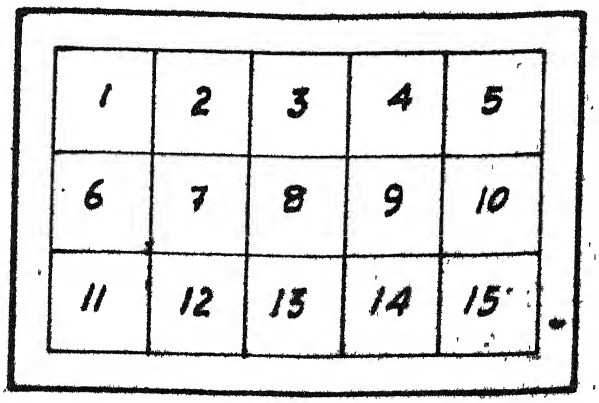
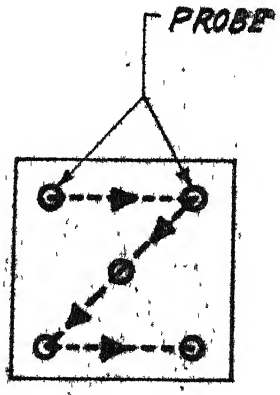




TOP
ZONES ON SCANNING FACE.



LOCATIONS
IN A ZONE

FIG. 4. DIMENSIONS OF THE BOND PLATE ZONES & LOCATIONS.

surface of the material under test and measurements are made of the potential difference at two other definite points using two other electrodes.

6.2.2 The tests were conducted in different zones on all the 6 plates. The following procedure was adopted:-

(i) The white metal surface was cleaned by petrol to remove oil, dust etc.

(ii) The reference standard bonded plate as supplied with the equipment and having markings of good and bad bonds was also cleaned similarly.

(iii) The zero position of the meter needle was set using Meter setting control.

(iv) The electrode surface probe was kept in contact on the reference standard plate and having a bad bond at "position X" marked thereon as shown in fig.5. The meter reading was set to maximum i.e. 10 divisions by adjustment of probe current control, depending on the thickness of the white metal examined or alternately set the needle to 1 Div. of the scale, with the probe kept in contact over the good area.

(v) The probe was traversed over the bonded plates in different zones, as shown in fig.6, and readings recorded as given in Annexure I. The defective areas caused the meter needle to

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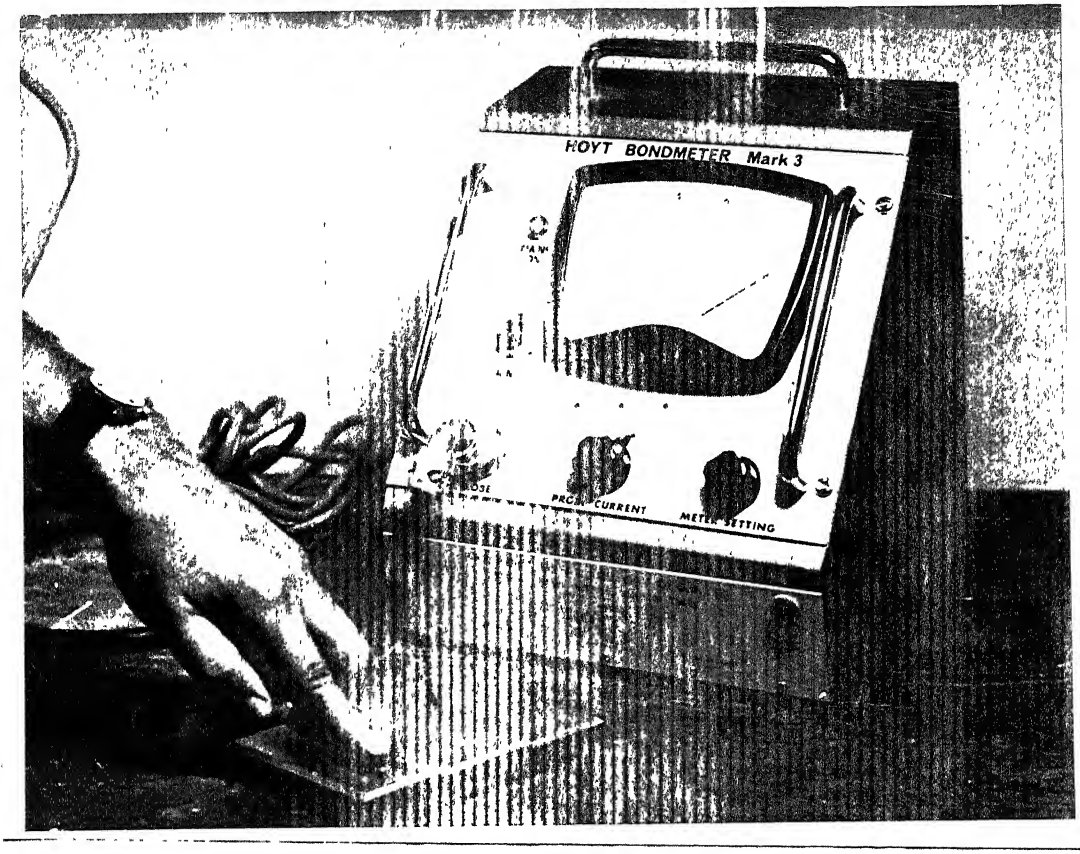

Fig.5 ELECTRICAL RESISTIVITY CALIBRATION ON STANDARD REFERENCE STEPPED BONDED BLOCK AT A DEFECTIVE BOND LOCATION.

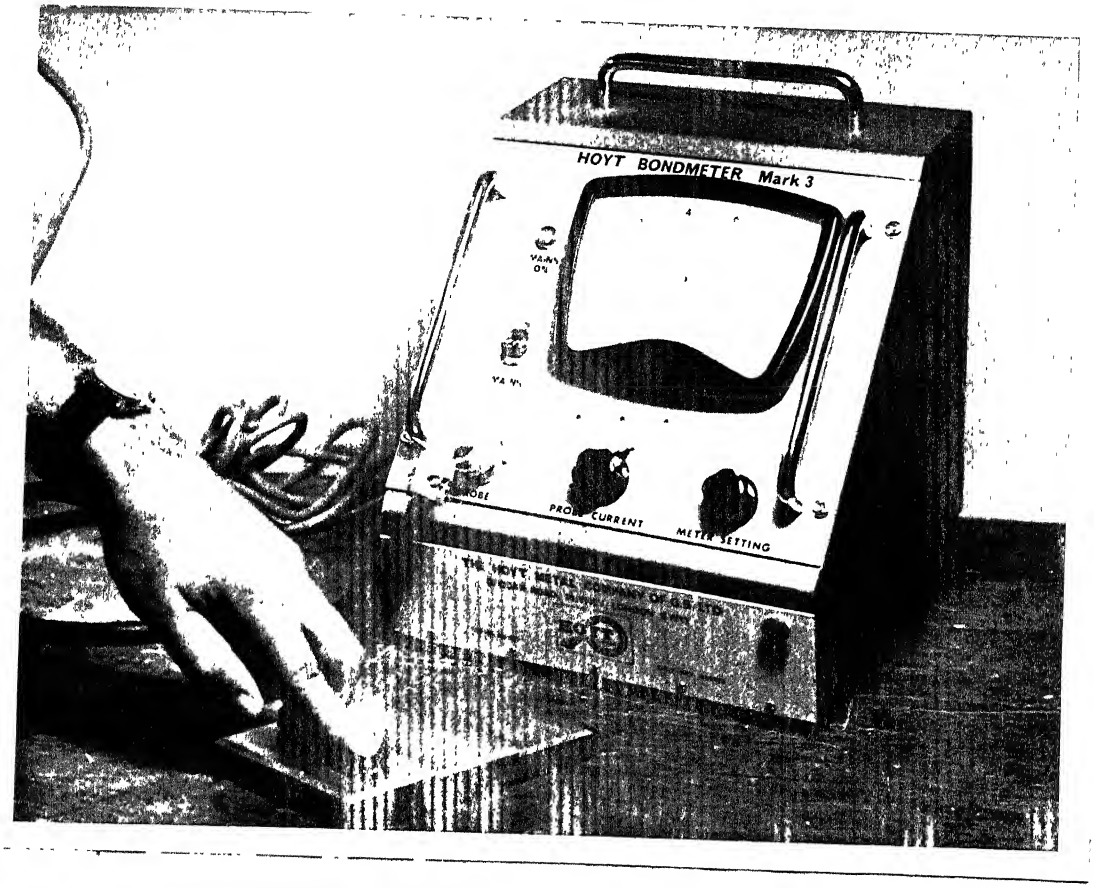

Fig. 6 ELECTRICAL RESISTIVITY MEASUREMENT ON BONDED TEST PLATE HAVING A DEFECTIVE BOND.

move beyond 5 Divns. to the right hand side. The difference between readings at different places on the plate was calculated to get a rough estimate of voids and oxide layers present in different zones.

6.3 MEASUREMENTS BY ULTRASONIC PULSE ECHO TECHNIQUE

The experiments were carried out using the ultrasonic flaw detector type "UFD67" manufactured by M/s Electronic Corporation of India Limited, Hyderabad. Longitudinal wave probes of different frequencies and diameters were used. With a view to evaluating degree of bond the following study and measurements were made in sequence:-

I. Measurement of Reflection & Transmission Coefficients on white metal/Bronze interface.

II. Study of ultrasonic pulse echo reflections, measurement of quotient of back reflection to bond reflection and corelation with electrical resistivity measurements.

III. Study of Multiple echo reflections from bond in between white metal/Bronze and white metal/steel bearing shells.

6.3.1 MEASUREMENT OF REFLECTION & TRANSMISSION COEFFICIENTS ON WHITE METAL/BRONZE INTERFACE

The acoustic velocity of longitudinal waves is related to the material properties. In order to measure Reflection & Transmission Coefficients on white metal/Bronze interface

as expressed in equations (18) and (19), it was necessary to find out the acoustic impedance i.e. product of density & velocity of sound of the two materials. The usual method for measurement is by using an Interferometer and precise reference blocks, permitting acoustic velocity to be measured to an accuracy of 0.1%. In absence of the above accessories and because this degree of high accuracy was not required, measurement of acoustic velocity was made by Immersion Technique[4] using the ultrasonic flaw detector and a transreceiver normal probe of frequency 2.5 MC/S & dia 20 mm as shown in fig.7. The method permits direct reading of acoustic velocity on the screen of the equipment. The procedure was as below:

(i) The circular calibration test block of bronze was at the base of the glass tank filled with water.

(ii) The probe partly immersed in water, was then positioned over the test block, so that its central beam was at right angles to the top face of the block and bottom of the tank.

(iii) The probe was connected to the ultrasonic flaw detector. The Material, Horizontal & Delay (Fine) controls were adjusted so that the reflected echo from the water-test block was on the zero line of the scale, the first echo from the backwall of the specimen was set on scale division 3.0, the second & third multiple reflections were on scale divisions 6.0 and 9.0 respectively, as shown in fig.8.

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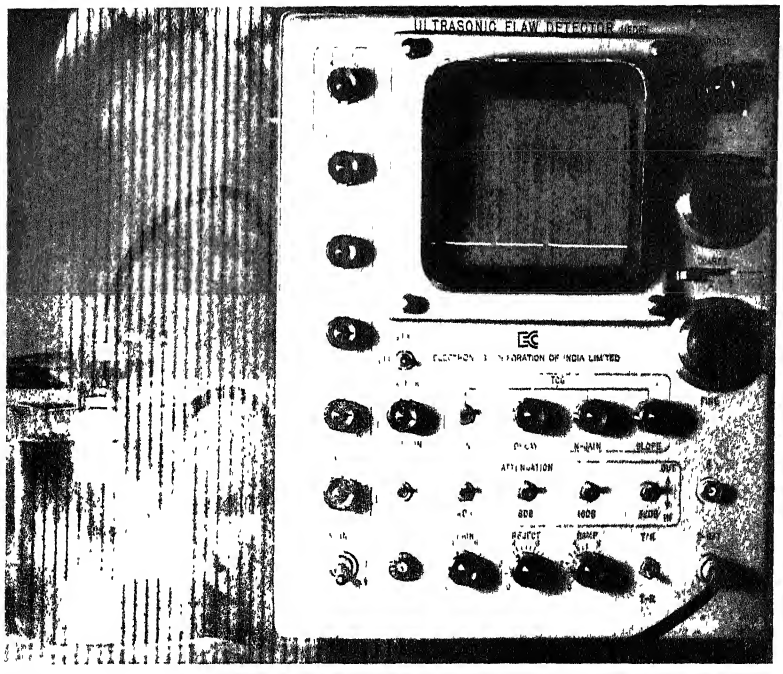

Fig.7 MEASUREMENT OF ACOUSTIC VELOCITY OF LONGITUDINAL WAVES USING IMMERSION TECHNIQUE.

(iv) The test block was removed from the tank & the scale division of the echo received from the bottom of the tank was noted. The numerical value of the acoustic velocity was (0.5 x No. of scale divisions) x 10^2 m/Sec. The basis of this method is given in detail in Annexure-II.

(v) The experiment was repeated using the white metal test block and the acoustic velocity was determined.

The acoustic impedance as calculated for the Bronze & white metal used for the experiment are given below:

TABLE II: ACOUSTIC IMPEDANCE OF BRONZE & WHITE METAL

Material	Number of scale Divs.	Acoustic velocity (longitudinal) x 10^3 m/Sec.	Density x 10^3 kg/m^3	Acoustic impedance x 10^6 kg/m^2 Sec.
BRONZE	9.1	4.55	8.85	40.05
WHITE METAL	4.9	2.45	11.8	28.9

The Reflection and Transmission Coefficients at white metal - Bronze interface i.e. when the ultrasonic waves are transmitted from white metal to Bronze backing plate, are

Reflection Coefficient $\alpha_r = \left(\frac{R_2 - R_1}{R_1 + R_2}\right)^2 = \left(\frac{40.05 - 28.9}{40.05 + 28.9}\right)^2 = 0.026$

Transmission coefficient $\alpha_t = \frac{4R_1 * R_2}{(R_1 + R_2)^2} = \frac{4 \times 28.9 \times 40.05}{(40.05 + 28.9)^2} = 0.973$

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The values of α_t is 0.973 & of α_r is 0.026 indicating that a fairly good acoustical coupling between white metal - Bronze will occur if bonding is good. The reverse i.e. transmission of acoustic waves from Bronze to white metal will not be good as value of reflection coefficient will be - 0.026. The negative sign indicates the reversal of the phase relative to the incident wave.

In case of a bad bond when there is a void or porosity, i.e. a boundary with air exist at interface. Air has a very low acoustic impedance of $0.0004 \times 10^6 kg/m^2s$ so that for the interface white metal to air the coefficient of reflection differs from the value 1 only by approximately 1×10^{-6} & hence at the interface reflection would take place from a bad bond.

6.3.2 EXPERIMENTAL METHODS FOR QUALITY EVALUATION OF BOND AND FOR DEFECT SIZE ESTIMATION

6.3.2.1 METHODS FOR EVALUATION

The evaluation of bond characteristics by ultrasonics can be carried out by following any of the methods given below depending on the thickness of the anti-friction metal lining and material used for the backing plate:

(i) Evaluation by pulse echo reflection using normal probes, preferably combined Transmitter & Receiver type and of frequencies suited to material under test, by direct contact with the test plates using oil or grease as a couplant.

(ii) Evaluation with normal probe by multiple reflection technique.

(iii) Evaluation with normal probe employing gap scanning and the immersion technique.

(iv) Evaluation with two normal probes of same frequency, but of different diameters, by the transmission-immersion technique.

The methods of evaluation as given in (i) and (ii) above were followed for the experiment using a combined double probe with a suitable perspex mounting with a view to avoiding the dead-zone of the transmitted pulse.

6.3.2.2 METHODS FOR DEFECT SIZE ESTIMATION

In order to preserve continuity of transmission of ultrasonic waves, the acoustic pressure at the interface of metallic bond must be same on both the sides as given in equation (14) and hence the reflected acoustic pressure is proportional to the amplitude of the reflected echo appearing on the screen. This fact has been utilised for the measurements.

In order to avoid the influence of surface condition on acoustic transmission efficiency, the white metal probing face was already machined earlier. Since the composition and internal structure can influence acoustic attenuation in plates hence the standard test blocks of same composition as used for test plates were casted and machined for time-scale calibration.

6.2.3 STUDY OF ULTRASONIC REFLECTIONS, MEASUREMENT OF THE QUANTUM AND CORRELATION WITH ELECTRICAL RESISTIVITY

The scanning was carried out as in fig.9 from white metal face, on all the ninety zones of the six test plates. A combined normal probe with perspex mounting was used for the experiment. The crystals were lead zirconate titanate of 2.5 MC/Sec. and 15 mm dia. The couplant used was Motor oil SAE-40. Where there was rough machining marks or depressions grease was also used. The test procedure followed was as below:-

(i) The time base was calibrated using the test blocks of White metal & Bronze. The calibration factor for the two metals was used for setting of back reflection from bottom of the bonded plates & for study of reflected echoes from the bond.

(ii) Testing was carried out, at 2-3 locations in a zone so as to cover the area. The maximum amplitude of reflections as obtained was recorded.

(iii) The ultrasonic reflections as from zones A-8, A-12, B-10, C-9 and E-7 consisted of an initial echo from perspex/white metal interface and a back echo representing the back surface of the test plates, indicating a good bonding between white metal-Bronze. A typical trace pattern as obtained is shown in fig.10.

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(iv) The probe was set on any of the good locations and back echo height was set to 4 Divisions of vertical scale by adjustment of gain control. The reject control was adjusted to get a clear trace pattern.

(v) Ultrasonic reflections as from zones A-3, A-14, B-6, and B-12 indicated flaw echo near to the initial echo and also effecting the amplitude of the back echo, as shown in fig.11. The relative amplitude of back echo to flaw echo was recorded and quotient determined for the zones as in Annexure-III. In a few cases it was observed that rotation of the probe along its vertical axis and variation of pressure on the probe effected the height of signals. The reasons can be due to non-parallelism of the two surfaces or due to bad contact of probe on the scanning face. In such cases, maximum height observed was recorded.

(vi) Ultrasonic reflections as from B-11, C-1 to C-3, C-13, C-15, and E-2 gave rise to a prominent flaw echo with multiple reflections due to presence of a very bad bonding. It can be seen from the fig.12 that there was a complete absence of back echo

indicating a clear separation between white metal-bearing metal due to the presence of air and at interface or due to the skimming that might have gone into the antifriction metal.

(vii) Ultrasonic testing of zones e.g. D-5, D-13, E-6 and F-10 showed scattered reflections at higher gain setting of the instrument and did not indicate any bond echo, though the bond was tested to be bad by electrical resistivity measurement.

(viii) The test plates C, D and F were cut to ascertain the findings of ultrasonic observations and correlating with resistivity measurement. The quotient of back reflection to bond reflection when compared with resistivity measurement is also shown graphically in fig.15.

6.3.4 STUDY OF MULTIPLE ECHO REFLECTIONS FROM BOND IN [illegible] METAL-BRONZE AND WHITE-METAL -STEEL BEARINGS.

The tests were carried out by using immersion technique.

(a) WHITE METAL-BRONZE BEARINGS:-

The testing was carried out using the combined normal probe of 2.5 MC/Sec. and 1.25 MC/Sec. from the white metallic side. It was observed that even with full gain settings of the equipment, a number of multiple reflections of well defined slope could not

be obtained. This can be attributed to presence of internal defects in bronze backing plate, coarse grain structure of casting and due to high degree of dissipation of ultrasonic waves during multiple reflections in Bronze bearing plate.

(b) WHITEMETAL-STEEL BEARING SHELLS

The bearing having a white metallic lining of 1.5 mm and having steel shell of 30 mm was tested from steel face using a normal combined probe of 5 MC/Sec. A good bond produced a sequence of echoes with a uniform decrement of amplitude as shown in fig.13 while bad bonding produced an irregular trace pattern as in fig.14. The microphotograph of a bad bonding at Antifriction metal - steel interface is shown in fig.15.

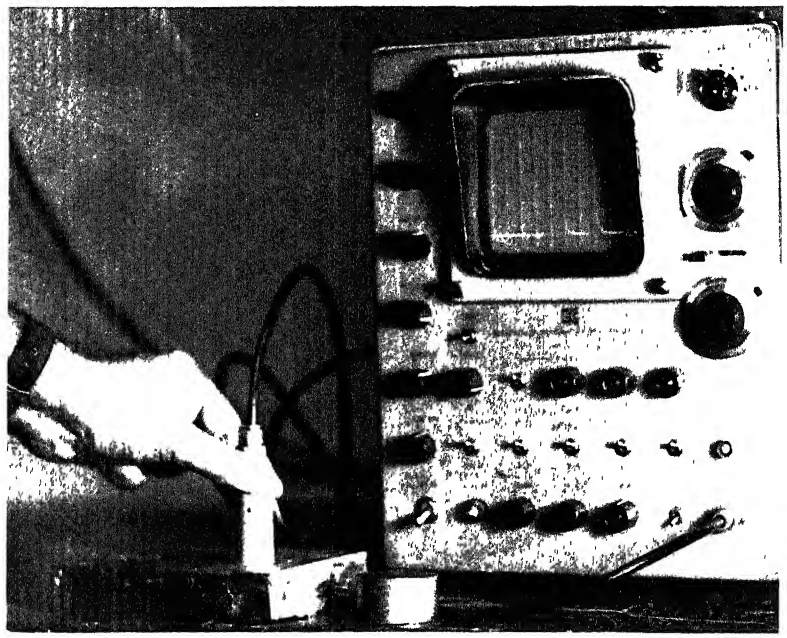

Fig.9 ULTRASONIC SCANNING OF A BONDED TEST PLATE BY PULSE ECHO REFLECTION TECHNIQUE USING ULTRASONIC FLAW DETECTOR.

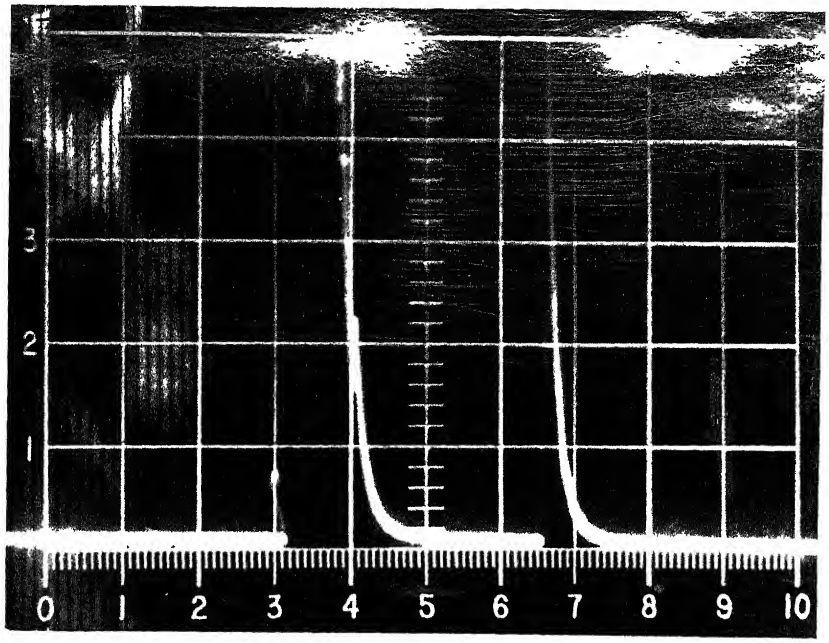

Fig. 10 OSCILLOGRAM, SHOWING INITIAL ECHO AND BACK ECHO FROM A HOMOGENEOUS BONDING.

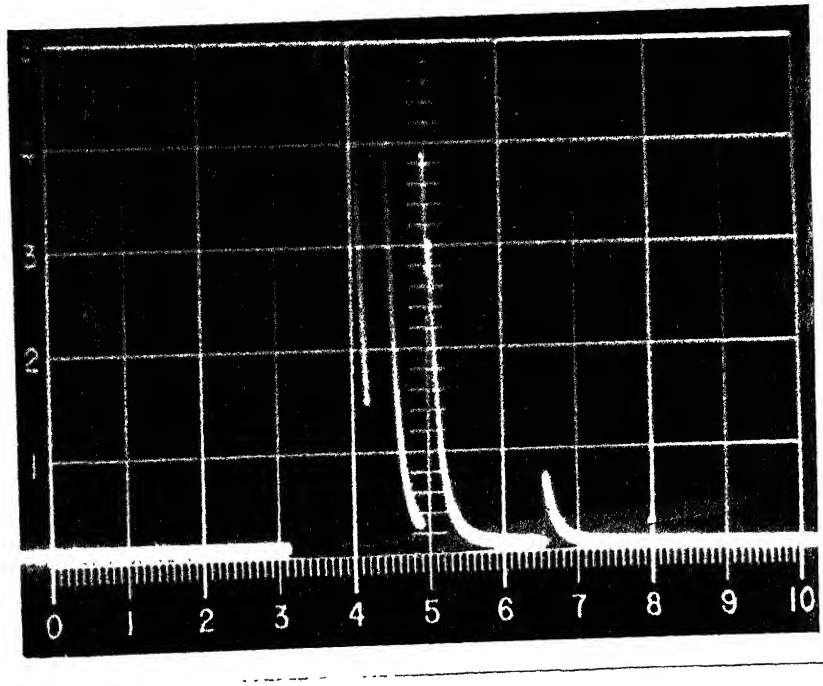

Fig. 11 OSCILLOGRAM SHOWING INITIAL ECHO, FLAW ECHO & BACK ECHO FROM A BAD BONDING.

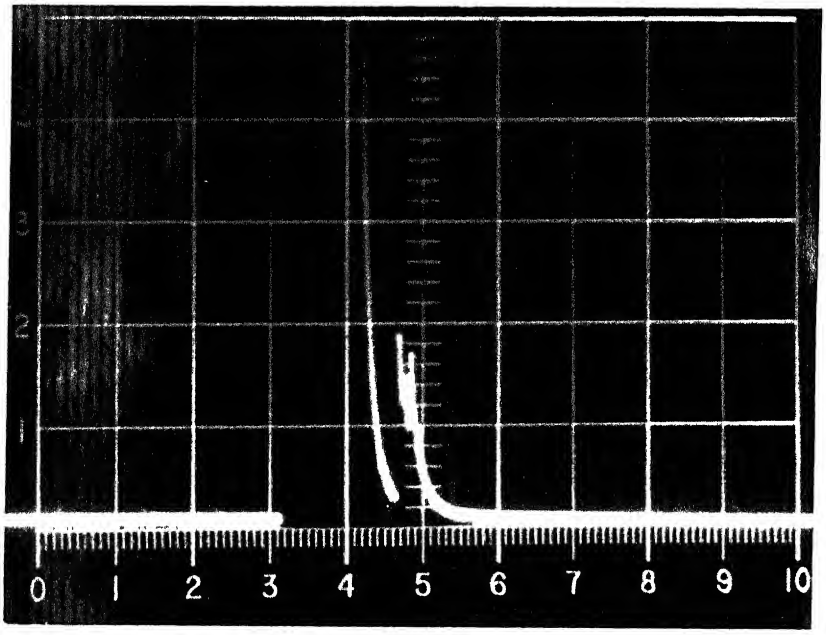

Fig 12. OSCILLOGRAM SHOWING FLAW ECHOES WITH ABSENCE OF BACK ECHO FROM A VERY BAD BONDING.

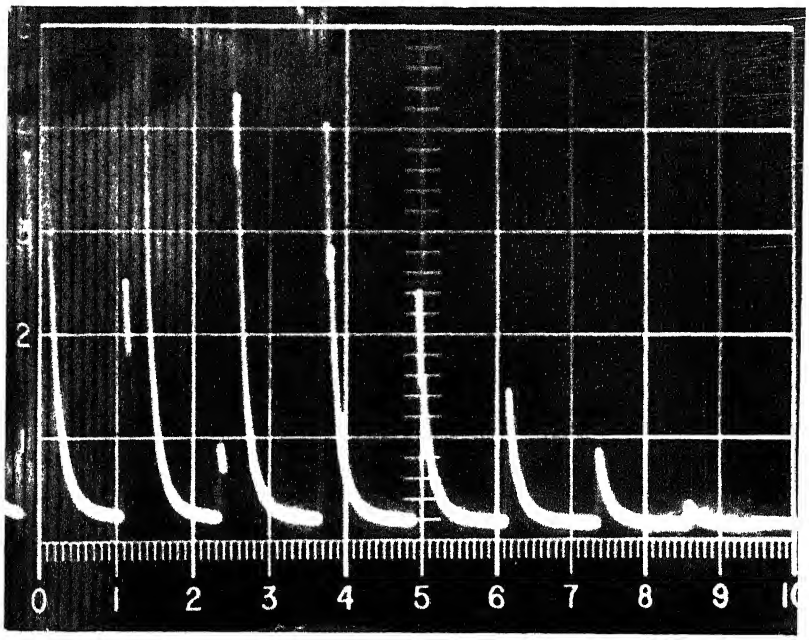

Fig. 13. MULTIPLE REFLECTIONS SHOWING A CLEAR SEQUENCE OF ECHOES FOR A HOMOGENEOUS BONDING.

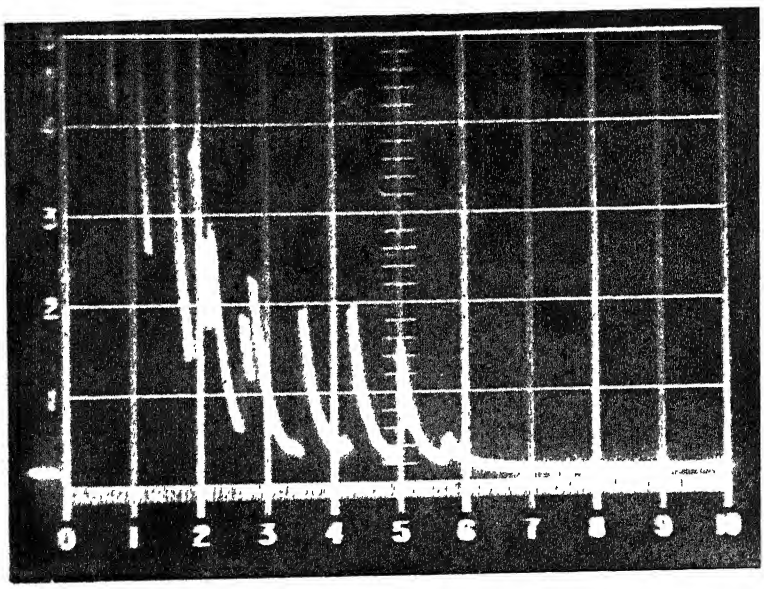

Fig. 14. MULTIPLE REFLECTIONS SHOWING DISCONTINUITY OF ECHOES FROM A BAD BONDING.

Fig. 16 MICROPHOTOGRAPH OF A BAD BONDING AT ANTIFRICTION METAL - STEEL INTERFACE.

7. DISCUSSIONS & CONCLUSION

7.1 Detection and evaluation of bonding become easier if reflection and transmission coefficients of the materials used in bearings or clad plates are known. When the ultrasonic waves were transmitted in White metal and Bronze standard test blocks the transmission and reflection coefficients were found to be 0.973 and 0.026 respectively. Expressed as percentages the reflected wave has 97.3% of the acoustic pressure of the incident wave and the transmitted wave 2.6%. In practice, these percentages may vary depending on the chemical composition, structure, presence of internal defects, and on acoustic anistropy of the materials. Ultrasonic testing and subsequent metallurgical investigations of zones C-7, D-5, D-8, D-13, D-15, F-3, F-9,10 and F-14 indicated scatter of ultrasonic reflections. The degree of dissipation of ultrasonic waves depended on the extent and type of voids, inclusions present in the cast metals.

7.2 The bonded test plates and bearing shells with white metal lining of thickness 5 mm and 1.5 mm respectively when tested ultrasonically by direct contact and immersion testing methods indicated that bearings having antifriction lining of thickness 4-5 mm can easily be tested by the former method using a double combined normal probe with a matching perspex contact shoe. Thin lined bearings can be tested effectively by immersion testing by normal pulse echo reflection or by Multiple Reflection

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Technique. The selection of frequency of the probe depended on the material of antifriction metal lining and base metal. The experiments indicated that probes of frequency 2.5 MC/Sec. and 1.25 MC/Sec. are well suited for bearings having bronze backing. Flaw detectability was good with the use of probes of 5 MC/Sec. for bearings having steel backing.

7.3 The equipment for bond testing should have good sensitivity and high resolution. The test equipment efficiency should be assessed by combined performance of Ultrasonic Flaw Detector and Probe. The equipment used for evaluation of bonding should have good "Sensitivity" & "Resolution". Sensitivity is the measure of ability of the test equipment to detect flaws, based on the size of the defect detectable and the height of indication obtained. "Resolution" implies the ability of the test equipment to display clearly on the screen the echoes from two reflectors located close together. The experiments using normal probes indicated that the equipment used for bond evaluation should have a good sensitivity and high resolution.

7.4 The ultrasonic reflections and metallurgical investigations of zones C-6, D-5, D-10, D-13, F-10, F-12 and F-14 indicated that the bonding was found to be good whereas electrical resistivity measurements indicated presence of bad bonds. It was found that the base plate in

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these zones was having slag entrapment, blow holes and cluster of porosity, indicating that the electrical resistivity method for bonding is better suited for thin bearings and clad plates free from material defects.

7.5 The qualitative or quantitative evaluation and estimation of bond can be done by finding out quotients of back to bond reflections. The experiments and comparative examinations of zones by electrical resistivity and ultrasonic measurements have indicated that the greater the quotient, more homogeneous will be the bond. The "surface conditions" of the test surface influenced the transmission of ultrasonic waves in the material while the "internal structure", micro and macro influenced the acoustic attenuation of the material. Both factors threw of off a few results considerably.

The experiments indicated that the quotients, have to be determined for combination of the material used in the bearings or clad plates to arrive at acceptable and non-acceptable limits desired from service point of view. The corelation of quotients with electrical resistivity values in case of white metal-Bronze bearing plates indicated that quotient 1.5 and above can be considered as acceptable bonding.

....37

The quotients can be precisely determined by immersion technique. The evaluation can also be made to a greater accuracy by using ideal reference flaws such as flat bottom holes of different diameters, notches and cuts in reference standard test blocks. The attenuation in dB can be related to amplitude of reflections.

7.6 The experiments showed that Multiple reflection technique was not satisfactory for thick and cast bronze backing plates in a bearing due to high degree of dissipation of ultrasonic energy. The technique is well suited for thin lined bearings and for bearings having steel backing shell.

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ANNEXURE-I

ELECTRICAL RESISTIVITY CHARACTERISTICS OF BONDED PLATES IN DIFFERENT ZONES

TEST PLATE NO. A

ZONE NO.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
A-1	4.7 3.0	2.7 2.2	1.5 2.0	5.0 4.2	7.0 5.2	A-1e
A-2	4.4 4.2	2.6 4.0	5.8 4.2	3.5 5.0	3.8 3.7	-
A-3	6.2 6.2	4.2 3.1	3.3 3.2	3.8 5.5	3.0 3.9	A-3a
A-4	6.2 2.0	1.0 1.2	2.0 4.2	3.2 2.2	2.6 3.8	-
A-5	2.7 4.5	3.0 5.5	4.4 3.0	3.2 2.6	6.3 4.0	A-5e
A-6	3.8 3.0	4.8 3.5	4.8 4.0	2.9 2.4	3.7 2.2	-
A-7	2.5 5.0	3.2 3.2	4.8 4.5	3.6 5.5	5.0 4.9	-
A-8	2.8 1.8	1.0 1.8	4.4 3.8	3.2 0.8	1.2 2.2	A-8b
A-9	2.8 0.8	2.4 1.0	4.4 2.4	1.8 1.4	2.2 2.6	-
A-10	3.0 2.2	4.5 3.8	6.0 5.0	2.8 4.4	3.5 4.2	-
A-11	2.8 2.2	3.0 2.8	2.6 2.2	3.6 2.8	2.8 3.2	-
A-12	4.4 3.0	1.8 1.4	2.2 1.8	1.8 1.8	0.6 0.6	A-12e
A-13	3.0 1.2	2.8 1.4	1.7 2.0	1.6 1.8	2.0 1.3	-
A-14	6.0 5.8	5.0 4.0	1.8 1.2	3.2 2.6	4.5 2.7	A-14a
A-15	3.0 1.5	2.0 3.5	1.2 2.2	1.7 2.8	2.6 0.8	-

ANNEXURE-I contd...

TEST PLATE NO. B

ZONE NO.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
B-1	4.5 7.0	5.0 8.0	5.0 6.5	7.2 2.0	8.0 6.5	B-1 e
B-2	4.6 3.8	5.2 4.4	4.2 4.2	4.3 4.1	3.8 3.4	-
B-3	4.0 5.2	4.4 5.4	4.7 5.7	3.7 3.0	3.8 4.8	-
B-4	5.4 4.5	2.7 2.7	6.8 4.5	4.5 3.8	4.2 4.0	B-4c
B-5	4.2 7.5	4.6 5.0	3.8 5.0	4.0 3.8	4.4 3.7	-
B-6	8.4 3.8	7.6 4.6	8.5 2.7	9.4 3.8	10.0 4.2	B-6e
B-7	5.2 3.8	4.4 2.7	3.9 3.4	5.8 4.6	2.4 2.9	-
B-8	3.5 1.5	3.0 1.5	2.4 1.0	2.4 1.5	2.5 2.4	-
B-9	3.0 2.3	2.0 2.6	2.0 2.4	2.2 1.5	2.2 2.0	-
B-10	3.2 3.8	3.4 3.6	4.7 3.9	2.4 3.6	2.7 2.9	B-10b
B-11	10.0 7.8	10.0 9.0	10.0 10.0	6.4 6.6	10.0 8.2	B-11c
B-12	2.4 5.4	5.2 5.7	9.0 7.0	10.0 8.8	10.0 10.0	B-12c
B-13	5.9 5.2	6.0 4.8	6.8 7.2	10.0 8.8	10.0 10.0	-
B-14	3.5 4.4	3.5 4.5	4.7 5.0	5.5 9.8	8.5 10.0	-
B-15	4.0 7.4	4.5 9.0	5.8 7.8	6.0 6.8	7.6 4.5	-

[illegible] PLATE No.C

ZONE No.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
C-1	8.6 6.5	5.9 8.0	6.2 7.5	10.0 10.0	9.0 8.4	C-1d
C-2	9.2 8.1	6.5 9.0	9.2 8.5	6.9 8.0	5.4 5.2	-
C-3	10.0 10.0	9.8 9.0	9.7 8.5	5.5 8.0	4.8 6.0	C-3b
C-4	4.8 10.0	5.5 10.0	4.5 8.0	5.2 6.0	6.0 10.0	-
C-5	10.0 10.0	10.0 9.5	10.0 9.8	5.8 9.2	5.2 6.8	-
C-6	8.4 7.5	8.4 7.4	6.0 6.5	8.3 5.4	7.5 5.9	C-6b
C-7	5.0 6.2	5.2 5.2	5.0 3.8	4.4 3.5	6.4 3.4	-
C-8	4.2 6.2	4.2 5.8	4.5 5.0	4.8 5.3	5.4 4.8	-
C-9	5.2 6.2	4.7 4.3	4.4 5.2	3.9 5.5	3.2 5.5	C-9c
C-10	4.2 7.4	4.0 8.6	3.8 7.2	3.7 6.2	2.8 6.7	-
C-11	9.2 5.9	9.4 6.5	10.0 6.9	10.0 7.8	9.2 8.6	-
C-12	4.2 4.6	4.9 5.4	5.5 6.7	6.0 6.2	8.8 7.0	-
C-13	5.2 6.0	4.2 4.0	6.2 4.2	4.8 5.0	6.0 10.0	C-13c
C-14	3.7 5.2	5.3 5.0	4.2 3.8	5.5 4.4	10.0 10.0	-
C-15	4.2 10.0	4.8 7.8	5.0 7.8	3.6 8.5	8.9 10.0	C-15e

ANNEXURE-I contd...

Sheet No. D

ZONE NO.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
D-1	7.4 4.6	6.5 3.5	7.2 4.8	6.8 4.4	8.2 4.8	-
D-2	3.8 5.0	4.2 5.4	4.8 4.0	4.2 4.0	5.0 3.2	D-2c
D-3	2.2 4.5	6.2 4.9	5.0 4.6	6.5 5.4	5.0 5.8	-
D-4	5.2 4.7	6.8 4.5	5.4 2.8	6.7 5.4	5.0 4.8	-
D-5	10.0 6.4	10.0 7.2	10.0 7.4	10.0 6.6	10.0 7.0	-
D-6	4.1 3.8	6.4 3.7	4.2 4.5	4.8 6.2	4.6 5.0	-
D-7	4.9 3.6	4.8 4.7	5.0 4.7	5.2 4.5	5.0 4.8	-
D-8	5.8 4.6	6.0 4.2	5.2 5.1	4.8 5.2	4.2 4.8	-
D-9	10.0 4.8	10.0 5.5	10.0 5.8	10.0 6.3	10.0 10.0	D-9b
D-10	5.8 5.8	4.5 4.8	5.2 7.2	6.8 8.4	10.0 10.0	D-10e
D-11	5.7 5.2	6.4 3.9	6.5 4.8	7.9 5.6	10.0 10.0	-
D-12	5.0 6.0	4.5 3.8	5.6 5.5	5.1 5.6	10.0 10.0	D-12d
D-13	4.6 3.2	5.6 7.2	3.0 2.0	4.0 1.0	3.5 7.0	-
D-14	2.0 4.3	4.2 4.6	5.8 3.8	4.5 6.0	7.0 6.2	D-14a
D-15	6.5 7.2	4.8 3.7	2.9 6.2	8.0 3.4	6.7 7.5	-

TEST PLATE NO.E

ZONE No.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
E-1	5.5 3.8	6.5 1.8	4.8 1.7	3.4 4.9	2.8 2.5	-
E-2	2.4 10.0	3.8 10.0	3.4 9.8	2.8 7.8	4.0 5.0	-
E-3	10.0 4.0	10.0 4.7	10.0 4.0	7.8 5.5	4.7 2.6	E-3b
E-4	2.6 2.8	2.4 2.4	4.0 1.2	3.8 2.2	3.0 1.7	-
E-5	4.4 10.0	3.2 10.0	4.2 10.0	5.2 10.0	4.2 8.8	-
E-6	6.7 5.4	6.5 1.9	7.0 1.9	9.8 2.0	10.0 2.0	-
E-7	2.0 2.2	1.8 2.3	0.5 3.4	1.2 4.1	1.8 3.2	E-7a
E-8	2.4 1.8	2.8 2.6	2.7 2.1	2.2 3.0	2.6 3.2	-
E-9	2.6 2.0	3.0 1.9	2.8 1.0	3.2 2.7	3.8 4.0	-
E-10	3.2 6.0	2.6 4.7	2.5 4.2	3.4 5.2	2.9 5.2	E-10c
E-11	3.4 6.0	6.7 2.4	10.0 4.8	10.0 10.0	10.0 10.0	-
E-12	3.4 5.0	3.8 4.8	2.2 4.2	5.8 5.0	6.2 5.6	-
E-13	3.8 10.0	5.2 1.8	4.0 4.0	4.4 4.0	6.1 5.5	-
E-14	5.7 5.4	4.6 5.0	5.9 5.8	6.8 5.2	10.0 8.5	E-14e
E-15	5.4 10.0	6.2 10.0	5.8 10.0	6.2 9.7	10.0 9.2	-

ANNEXURE-I contd..

TEST PLATE NO.F

ZONE NO.	RESISTIVITY VALUES IN DIVISIONS AT VARIOUS LOCATIONS					Zone location investigated
	a	b	c	d	e	
F-1	1.7 2.7	3.8 3.2	2.0 3.6	2.2 4.2	4.2 3.6	-
F-2	4.5 3.5	3.9 2.9	4.8 2.8	4.5 1.7	4.5 2.2	-
F-3	2.2 1.8	3.8 2.0	2.0 1.8	2.4 2.4	2.4 1.5	F-3c
F-4	3.6 2.5	3.7 2.8	2.2 4.5	4.2 6.0	3.5 5.0	-
F-5	2.4 4.0	4.5 4.2	6.5 4.2	7.0 5.5	10.0 6.5	-
F-6	5.0 3.8	3.2 4.5	4.0 5.3	4.6 3.8	3.8 3.2	-
F-7	2.2 3.2	1.8 2.4	3.8 2.7	2.5 3.5	4.2 4.8	-
F-8	3.7 3.5	3.4 4.2	3.2 4.8	2.5 5.0	2.7 3.5	-
F-9	10.0 9.8	7.5 9.8	9.4 9.8	9.8 10.0	6.7 9.0	F-9c
F-10	10.0 9.8	10.0 10.0	9.5 9.8	10.0 10.0	10.0 10.0	F-10d
F-11	5.5 6.8	5.7 8.0	4.8 7.8	8.9 9.8	10.0 9.9	-
F-12	2.2 6.2	5.2 5.4	4.4 5.8	4.7 4.8	8.5 8.5	F-12c
F-13	5.2 6.2	5.8 8.5	5.4 8.0	8.5 8.2	9.0 10.0	F-13a
F-14	6.5 7.2	8.2 9.5	3.2 6.5	5.2 6.9	7.5 8.0	-
F-15	3.7 6.8	2.8 4.9	6.8 5.6	7.8 9.5	10.0 9.2	-

MEASUREMENT OF ACOUSTIC VELOCITY BY IMMERSION TECHNIQUE.

(1) METHOD OF MEASUREMENT

The following method permits direct reading of acoustic velocity of a material on the screen of the ultrasonic flaw detector.

The specimen, which must be plane-parallel at one point, is placed in a tank of water. An immersion probe is then positioned so that its beam is at right angles to the bottom of the tank. The probe is connected to an ULTRASONIC FLAW DETECTOR having variable Scale Expansion. The instrument is then adjusted so that the echo from the water-specimen interface is on the zero line of the scale (Fig 8 A), the first echo from the back wall of the specimen is on scale division 3.0. A five-division scale can be employed for acoustic velocities of less than 5000 meters/sec. for direct reading.

If the specimen is then removed from the tank the first echo received from the bottom indicates the numerical value of the acoustic velocity as in fig. 8 (B).

Acoustic Velocity = 0.5 x No. of Scale Divisions $\times 10^3$ m/Sec.

(2) THEORETICAL EXPLANATION:-

The explanation is simple.

If the time taken for sound to travel through the specimen is t_m and to travel through the water column

Contd.....2/-

is t_w then it can be written that

$$\frac{t_m}{t_w} = \frac{V_w}{V_m}$$

V_w = acoustic velocity in water

V_m = acoustic velocity in the material.

This means that the transit times are in inverse relationship to the associated acoustic velocities.

Thus

$$V_m = \frac{t_w}{t_m} V_w$$

But transit times t_m and t_w have the same relationship has distances "a" and "b".

Therefore

$$\frac{t_m}{t_w} = \frac{a}{b}$$

which means that V_m can be expressed as :-

$$V_m = \frac{b}{a} \times V_w$$

If now the numerical value of V_w (approx. 1500 or, to be exact, 1485 at 20° C) is taken for (a), then

$$V_m = b$$

That is, to say, the value of the scale read off for b corresponds to the value of the acoustic it is desired to ascertain.

By the afore-described method these tolerances can be measured to an accuracy of ± 0.5 -1.0% depending upon the linearity of time base of the equipment used.

ANNEXURE - III.

ELECTRICAL RESISTIVITY VALUES AND QUOTIENTS OF BACK REFLECTION TO BOND REFLECTION.

Sr. No.	Zone No.	Average Resistivity values Div.	Quotient	Remarks.
1.	A-3	4.24	1.5	Acceptable Bonding.
2.	A-14	3.68	1.85	-do-
3.	B-6	6.3	0.55	Non-acceptable Bonding.
4.	C-4 *	7.08	0.38	-do-
5.	C-5	8.53	0.22	-do-
6.	C-11 *	8.25	0.17	-do-
7.	D-9	8.34	0.31	-do-
8.	D-12	7.11	0.48	-do-
9.	E-14	6.2	0.28	-do-
10.	F-5 *	5.48	0.95	-do-
11.	F-6 *	4.12	0.4	-do- Cluster of porosity at the interface.
12.	F-12 *	5.5	0.50	-do- Fine lead entrapment at bottom of the base plate.

* Observations confirmed after sectioning the zone and thereafter by macro and micro-examination.

A 47760

Date Slip

This book is to be returned on the date last stamped.
